



Comparisons of Mayan forest management, restoration, and conservation

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ARTICLE INFO

Article history:

Received 6 May 2010

Received in revised form 16 October 2010

Accepted 7 November 2010

Available online 7 December 2010

Keywords:

Mexico

Belize

Lacandon Maya

Yucatec Maya

Mopan Maya

Tsotsil Maya

Resilience

Local ecological knowledge (LEK)

ABSTRACT

Numerous communities associated with at least five distinct ethnic Mayan groups in southern Mexico and Central America continue to rely upon forested areas as integral components of their agricultural systems. They carefully manage these areas so that forests provide food, raw materials, and animals. Management practices include removing and planting of woody and herbaceous species, apiculture, and seed harvest. Mayan agroforestry systems in geographically and ecologically distinct areas of Mesoamerica were evaluated to better understand traditional agroforestry system components and how indigenous Mayan agroforestry could be a part of regional forest conservation and restoration. Systems were within Mexican land grant areas (*ejidos*) or on contested land. Although these systems rely upon different woody species and management techniques, common among them are: (1) the use of multi-stage and successional pathways with forest as a part of the larger system, (2) species that are believed by traditional ecological knowledge (TEK) to accelerate forest regeneration – more than 30 tree species are recognized and managed as potential facilitators of forest regeneration and (3) direct human consumption of forest products at all stages of regeneration.

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1. Introduction

Environmental degradation in Mesomerica, as in many developing areas, is severe. For example, in Belize, Nations and Komer (1983) found an annual deforestation rate of 0.3%; by 1993, USAID found annual deforestation had climbed to 1.8% (Drew, 1999); and Emch et al. (2005) calculated a total net loss of 10% forest cover between 1975 and 1999 in southern Belize. In southern Mexico, annual deforestation rates are over 2% (Howard and Homer-Dixon, 1996). Between 1990 and 2000, Honduras and Guatemala lost 1% and 1.7%, respectively, of the forest annually (FAO, 2001; Tucker et al., 2005). These figures vary somewhat, but clearly deforestation in Mesoamerica, a biodiversity hotspot, is rapidly occurring. Land management practices, overwhelmingly dominated by conversion of forest and grassland to agriculture and ranching, represent a large reason for this loss.

Degraded environmental conditions result in socio-political discord, which escalates with increasing population pressures (Lal,

1995; Ram, 1997; Campbell and Anaya, 2008) through more complex standards of living (Dong et al., 2008). Struggles such as these have led to exploration of land management strategies and research into practices guided by traditional ecological knowledge in the developing neotropics and beyond (Altieri, 1995; Challenger, 1998; Diemont and Martin, 2009; Martin et al., 2010). Research has been undertaken on traditional systems as sources for novel crops (Plotkin, 1988). Challenger (1998) and Altieri (1995) link an understanding of indigenous systems to sustainable land use. Specific to Mesoamerica, Alcorn (1984), Nations and Nigh (1980), Atran (1993), Levy Tacher et al. (1991) and others have described Mayan agroforestry systems. De Clerck and Negreros-Castillo (2000) and others have examined Mayan home gardens. Atran (1999) describes the importance of local knowledge and indigenous commons areas. Gomez Pompa and Kaus (1999) describe the importance of incorporating local perspectives of resource use into national decision and policy-making. Research must be continued into local options that will revert land degradation while providing for subsistence agriculture by the people who live in these areas (Nicholson et al., 1995; Foroughbakhch et al., 2001; Li, 2004).

The Mesoamerican Biological Corridor (MBC) (Fig. 1) is an effort that could be tied to this need for land rights and conservation. Originally established in 1990 as the *Paseo Pantera*, with subsequent

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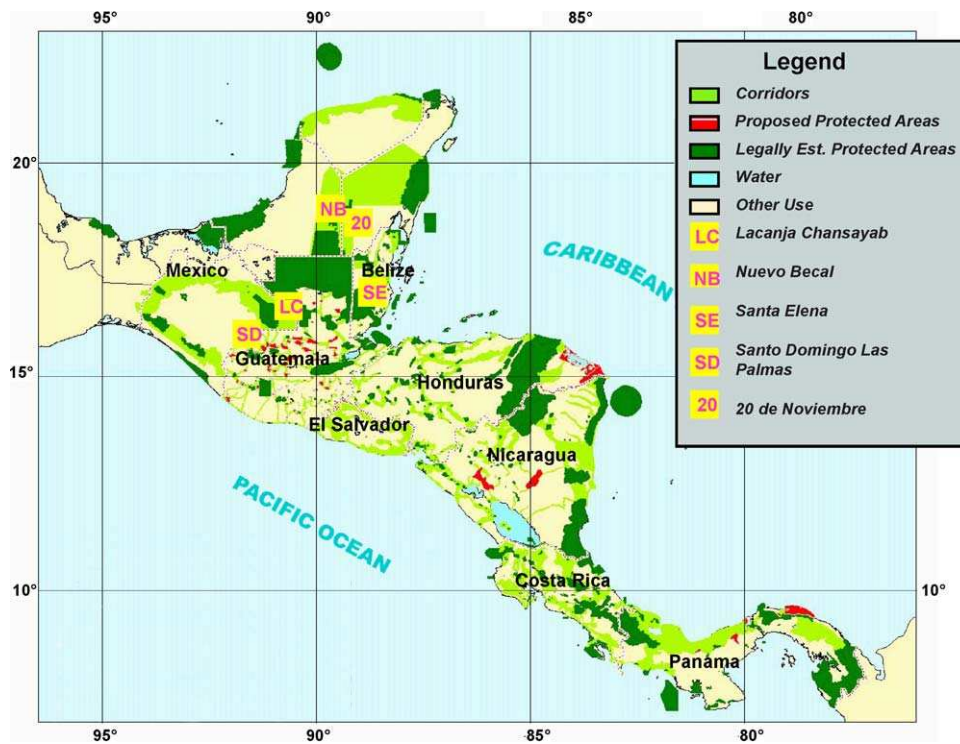


Fig. 1. Map of the Mesoamerican Biological Corridor (NASA/SERVIR) showing research locations Lacanja Chansayab, Mexico; 20 de Noviembre, Mexico; Nuevo Becal, Mexico; Santo Domingo Las Palmas, Mexico; and Santa Elena, Belize.

name change and mission revisions in 1997, the MBC aims to protect critically endangered wildlife species by allowing for migration throughout the organized region (Graham, 2003; CCAD-UND/GEF, 2003; Ray et al., 2006). The MBC aims to connect national parks, reserves, and private and communal lands in Mexico, Guatemala, Belize, Honduras, El Salvador, Nicaragua, and Costa Rica. However, much of the MBC remains unresolved gap areas, and land under private and communal use for subsistence agriculture. Restoration and conservative efforts must be expanded and altered to meet the difficulties imposed by the unique socio-political, economic, and environmental intricacies of Mesoamerica if such efforts will be met with success (Rivera et al., 2002; CCAD-UND/GEF, 2003).

Indigenous swidden agroforestry can be productive (Long and Nair, 1999; Nations and Nigh, 1980) while maintaining ecological integrity (Diemont and Martin, 2005; Diemont et al., 2006a,b; Wang and Young, 2003). Salafsky (1993) found when comparing agroforested to forested areas in Indonesia that over 80% of mammals discovered in the forested areas used agroforested areas as well. Wang and Young (2003) saw higher migratory bird use in traditionally agroforested regions compared to non-traditionally managed areas in Yunnan, China. Harvey and Gonzalez Villalobos (2007) discovered comparable bird and bat diversity in forested regions of Talamanca Reserve, Costa Rica, compared to agroforested areas surrounding the reserve. These facts support the contribution of indigenous agroforestry for better ecological management and conservation (De Clerck and Negreros-Castillo, 2000; Fox et al., 2000). This is a critical time for research into these Mayan practices in Mesoamerica because the oral traditions that preserve information related to these systems are in decline due to the increasing influence of Western culture (McGee, 2002; Diemont and Martin, 2009).

One example of Mesoamerican sustainable design is that of the Lacandon Maya of Lacanja Chansayab, Chiapas, Mexico. Their system of agroforestry (Table 1) is complex, productive, and appears to be based on agroecological principles that promote tools for both restoration and conservation (Quintana-Ascencio et al., 1996;

Diemont and Martin, 2009). The Lacandon Maya are indigenous forest farmers who live in the Lacandon rainforest in the Eastern lowlands of Chiapas, Mexico (Kashanipour and McGee, 2004). Their agricultural system employs a multitude of techniques for maintaining soil fertility and controlling pests, with minimal need for purchased inputs (Ewell and Merrill-Sands, 1987; Diemont et al., 2006a,b; Diemont and Martin, 2009). The Lacandon land-use system mimics forest succession (Kricher, 1999), while providing for human needs at all stages of the system (Diemont and Martin, 2009).

In addition to the productivity of the systems, studies have identified and studied native tree species that the Lacandon use to restore soil fertility and plant community (Table 2, Levy Tacher and Golicher, 2004; Diemont et al., 2006a,b). The leaves of the planted species *Ochroma pyramidale*, for example, appear to inhibit soil nematodes, which suggests a hindrance of leaf decay that accelerates soil organic matter accumulation under *O. pyramidale* (Diemont et al., 2006b). As many as 18 other native tree species are used by the Lacandon to accelerate forest recovery and restoration in the fallow (Diemont et al., 2006b; Diemont and Martin, 2009).

Over 30 Maya languages are currently spoken, and numerous agroforestry systems are in use by contemporary Maya living in Mesoamerica (Gasser, 2006). At least three of those groups, the Mopan Maya of Belize, the Itza Maya of Peten, Guatemala, and the Yucatec Maya of the Yucatan Peninsula, Mexico, speak similar languages to that of the Lacandon Maya (Sharer and Traxler, 2006). Lacandon Maya and the Mopan Maya migrated from Peten, Guatemala and/or the Yucatan Peninsula, Mexico less than four centuries ago. Unlike the Mexican Maya groups, which are in *ejido*, or community-owned systems, the Mopan Maya are on government reservations, which could influence management. In addition to those with historical and ethnic lines to the Lacandon Maya, numerous communities have sprung up in the past 50 years in geographically similar areas to that of the Lacandon Maya community of Lacanja Chansayab due to migration (Hernandez Castillo and Nigh, 1998); one example is the Tsotsil Maya community of Santo

Table 1
System Components of Lacandon, Yucatec, Mopan and Tsotsil Maya.

Community	Ethnic group	Field polyculture (species)	Coffee	Cacao	Ranching	Number of shrub stages	Number of forest stages	Use of fire for clearing
20 de Noviembre, Campeche, Mexico	Yucatec Maya	10–15	NP	NP	NP	1	2	x
Nuevo Becal, Campeche, Mexico	Yucatec/Tsotsil Maya	10–15	NP	NP	Few residents	1	2	x
Santa Elena, Toledo District, Belize	Mopan Maya	5–10	NP	Shade	NP	2	4	x
Santo Domingo Las Palmas, Chiapas, Mexico	Tsotsil Maya	10–15	Shade	NP	Half residents	1	2	
Lacanja Chansayab, Chiapas, Mexico (Diemont and Martin (2009))	Lacandon Maya	20–60	NP	NP	NP	2	3	x

NP, not present.

Table 2

Plant species used by Lacandon, Yucatec, Mopan and Tsotsil Maya to accelerate soil and plant community succession.

Community	Ethnic group	Plant species used for restoration
20 de Noviembre, Campeche, Mexico	Yucatec Maya	Cedrela odorata Hampea trilobata Pimenta dioica Swietenia macrophylla
Nuevo Becal, Campeche, Mexico	Yucatec Maya Tsotsil Maya	Brosimum alicastrum Bursera simaruba Cedrela odorata Lonchocarpus castilloi Piscidia piscipula Swietenia macrophylla
Santa Elena, Toledo District, Belize	Mopan Maya	Brosimum alicastrum Inga spp. (7 species) Ximenia americana Unidentified (pu pu te in Mopan Maya)
Santo Domingo Las Palmas, Chiapas, Mexico	Tsotsil Maya	Cecropia obtusifolia Cedrela odorata Croton draco Inga paterna Inga pavoniana Inga punctata Schizolobium parahyba
Lacanja Chansayab, Chiapas, Mexico (Diemont et al. (2006b))	Lacandon Maya	Astrocaryum mexicanum Belotia mexicana Brosimum sp Bucida buceras Calophyllum brasiliense Cedrela sp Cordia alliodora Dialium guianense Guatteria anomala Hampea stipitata Hibiscus sp Mucuna pruriens Ochroma pyramidale Piper auritum Piper aduncum Sapium lateriflorum Simira salvadorensis Sterculia apetala Swietenia macrophylla Unidentified (pok te in Lacandon Maya)

Domingo las Palmas. Similar migratory pathways, linguistic similarities, or similar ecoregions open the possibility of understanding how Mayan management adapts to new situations.

The presence of Mayan systems with geographic or close ethnic similarities to the Lacandon Maya allows for investigation of the question: How have different Maya groups come to rely on the similar tools used by the Lacandon: successional systems, forest use, and restoration species?

The objectives of this study were to:

- (1) Describe and compare agroforestry management of the Yucatec Maya of 20 de Noviembre and Nuevo Becal in the Yucatan of Mexico, the Mopan Maya of Santa Elena in southern Belize, and the Tsotsil Maya of Santo Domingo Las Palmas near Lacanja Chansayab to the agroforestry of the Lacandon Maya of Lacanja Chansayab, Mexico (Diemont et al., 2006a,b; Diemont and Martin, 2009).
- (2) Determine how tree species were used for ecosystem restoration by the Yucatec Maya of 20 de Noviembre and Nuevo Becal in Campeche, Mexico, the Mopan Maya of Santa Elena in southern Belize, and the Tsotsil Maya of Santo Domingo Las Palmas, Chiapas, Mexico.

2. Materials and methods

2.1. Study sites

Study sites were selected based on similarity to the Lacandon Maya in terms of ethnographic closeness (Share and Traxler, 2006) to the Lacandon Maya of Lacanja Chansayab (e.g., the Yucatec Maya and the Mopan Maya) and geographic closeness to the Lacandon Maya (Tsotsil Maya of Santo Domingo las Palmas (Fig. 1, Breedlove, 1973; Hernandez Castillo and Nigh, 1998). Mopan Maya are not part of an *ejido* system, community-owned land, but are instead on government reservation land.

The Yucatec Maya community 20 de Noviembre, Mexico (Fig. 1) is located at 18°10'39"N and 89°15'44"W. Mean annual rainfall is 1076 mm (INEGI, 2010), soils are karstic, and the surrounding vegetation is tropical sub-humid forest. Approximately 90% of families arrived from Dzitbalche in northern Campeche state. The *ejido* is one of the oldest (1969) in the region and encompasses 28,600 ha (Escamilla et al., 2000). Roughly 350 people reside in the community, with each family owning a 60–100 ha parcel for personal use; other land in the *ejido* is communally owned and managed.

The *ejido* land of Nuevo Becal (Fig. 1) is located at 18°30'40"N and 89°15'45"W and covers an area of 53,000 ha. The members are both Yucatec and Tsotsil Maya. The *ejido* was officially established in 1970 and is currently home to 420 people, allowing family parcel sizes of 300 ha. The surrounding vegetation is tropical sub-humid forest. Mean annual rainfall is 1076.2 mm, and soils are karstic.

The Tsotsil Maya of Santo Domingo Las Palmas, Mexico (Fig. 1) relocated to their present *ejido* and founded their community approximately 39 years ago due to conflict over land availability in the highlands of Chamula, Chiapas, Mexico. The community is located at 16°08'27"N and 91°19'03"W. The geography is similar to that of the Lacandon Maya. At the founding of the community, each member of the *ejido* of the Tsotsil Maya community of Santo Domingo Las Palmas, Mexico was granted 20 ha of land for cultivation.

The Mopan Maya of Santa Elena, Belize, 16°13'47"N and 89°6'31"W, live on reservation lands granted to them by the Belizean government (Fig. 1). Precipitation is 4100 mm annually. The Mopan Maya agroforestry system is approximately 30 ha. The government owns all reservation lands and can eliminate any Maya land rights at any time for any reason (Binford, 2007). The government has exercised this power on numerous occasions (Binford, 2007; D. Choc, Santa Elena, pers. comm.), granting logging and oil exploration rights on reservation lands to foreign companies.

The Lacandon community of Lacanja Chansayab, Mexico, is located at 16°45'30"N and 91°08'30"W and at an elevation of 400 meters. With a population of approximately 400, Lacanja Chansayab is *ejido* land and is one of three principal communities of the Lacandon Maya. The predominant soil type is Alfisol with a clayey texture and neutral pH. The surrounding vegetation is lower montane rainforest (Breedlove, 1973), and annual rainfall is 2500 mm (Diemont et al., 2006a,b).

2.2. Field sampling

In the communities of 20 de Noviembre, Mexico; Nuevo Becal, Mexico; Santo Domingo Las Palmas, Mexico; and Santa Elena, Belize community residents were questioned through semi-structured interviews during the period between June 2009 and March 2010. In the case of Lacanja Chansayab, Mexico, data of previous studies with similar methods were used (Diemont et al., 2006a,b; Diemont and Martin, 2009). Farmers were categorized as “key informants” (Tremblay, 1957) by the village leadership in each community. At least four farmers were interviewed in each community. Responses from each farmer were cross-checked with other key informants

in the community, and only responses with consistent agreement were used for system and management description. All interview questions were digitally voice recorded and simultaneously written. Farmers in each community were asked to describe the agroforestry system that they manage, developmental stages, and key plant species found in each stage. They were also asked to identify critical species essential for forest restoration. They were asked to identify those species known to enhance soil fertility or forest recovery.

Based on interviews, system diagrams (Figs. 2–4) were constructed as described in Odum (1996). All system inputs were determined (circle symbol) and how those system inputs flowed into system components. The boundary for the system was set at the farm level. System components were determined to be primary producer (bullet symbol), consumer (hexagon symbol), or storage (tank symbol), and flows (arrows) were arranged according to how energy flowed among system components.

Plant communities in agroforestry plots were sampled as in Diemont and Martin (2009), and used for evaluating use of forest restoration and soil enhancing species. Plant community sampling locations in each field-stage plot were determined using a transect method, with 10 samples at intersections of a 20-m grid. Sampling quadrats of 20–30 m² were assessed for plant community at each sampling point. In Santo Domingo las Palmas, a 10 by 20 meter quadrat was assessed. In the quadrats all plants with basal diameter 5 cm or larger were identified and counted. The traditional immediate use of each plant was determined from interviews with farmers. Immediately useful species were those plants that the farmers use for food, medicine, firewood, construction, or raw materials. Farmers were also asked whether the plant grew wild or was planted, whether the forest is managed for this plants survival and if so how. Species were identified by Maya or Spanish name and cross referenced with species lists in Nations and Nigh (1980) and Levy Tacher et al. (2002). Voucher specimens for all plants not previously collected and identified were collected and deposited in the herbarium at El Colegio de la Frontera Sur, San Cristóbal de Las Casas, Mexico. From this plant community assessment, plant use and management is reported here.

3. Results

3.1. Agroforestry systems

3.1.1. 20 de Noviembre, Mexico – Yucatec Maya

Rotational swidden agroforestry is practiced (Fig. 2 and Table 1) by the Yucatec Maya of 20 de Noviembre, Mexico. Within the system are one shrub stage and two forest stages. Approximately 10–15 species are found in the *milpa*. The *milpa*, herbaceous stage, supplies the family's primary grain and vegetable needs: corn, beans, squash, tomatoes, jalapeños, with other supplementary vegetables. No products grown in the *milpa* are marketed. *Milpa* clearing involves manual tree removal and a controlled burn on 2–4 ha of land. Before the burn, a fire barrier in the form of a shallow ditch is built to prevent fire spreading. Controlled burns for clearing occur at the beginning of the rainy season, usually in May and June to prevent fire spread and to ensure rain for newly planted seeds. After 2–4 years of harvesting, the *milpa* is left fallow; no harvesting or planting occurs for three years after abandonment. This fallow period is called *quamile* or *yerba* and is meant as a rest for the soil. After five years, in a stage called collectively *arbusto* (Spanish for shrub), nurse trees (see Section 3.2) are planted to encourage regeneration of a mature forest. Firewood for cooking is the primary harvestable product from *arbusto*. As the stand matures and has aged 10–25 years, bee colonies are located in this secondary forest to aid in pollination, and to take advantage of the many flowering

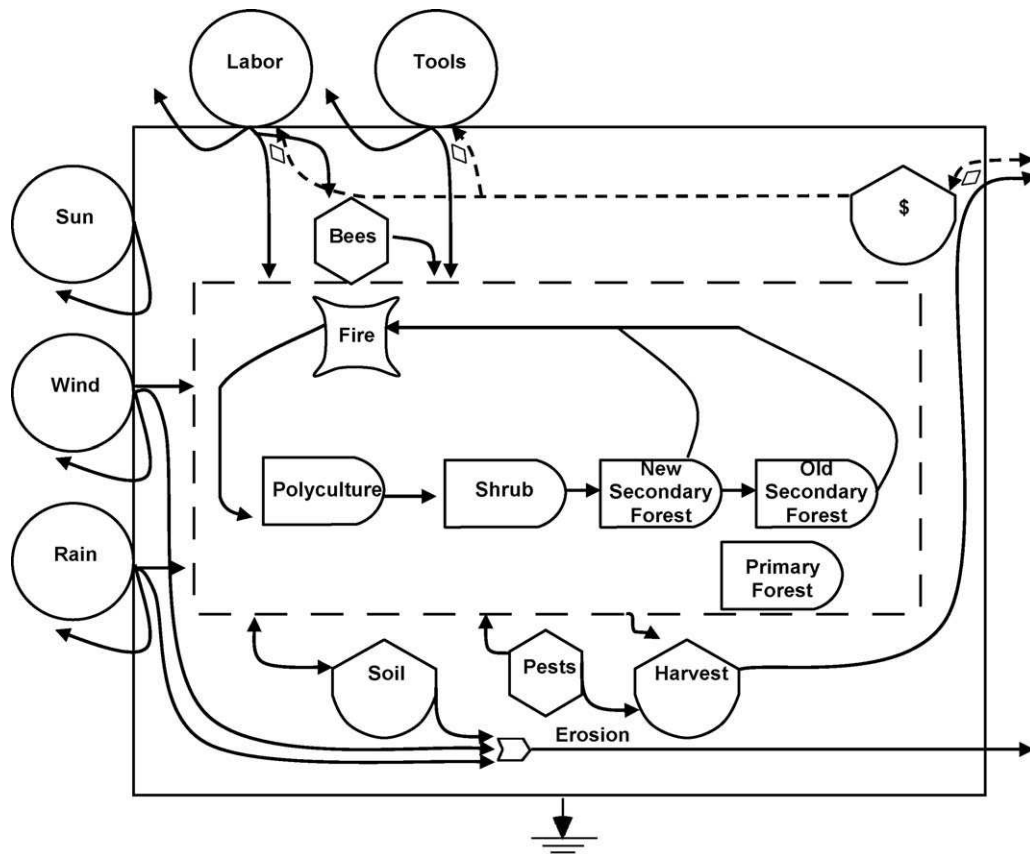


Fig. 2. Agroforestry system diagrams of 20 de Noviembre and Nuevo Becal, Mexico. Odum (1996) diagramming is utilized.

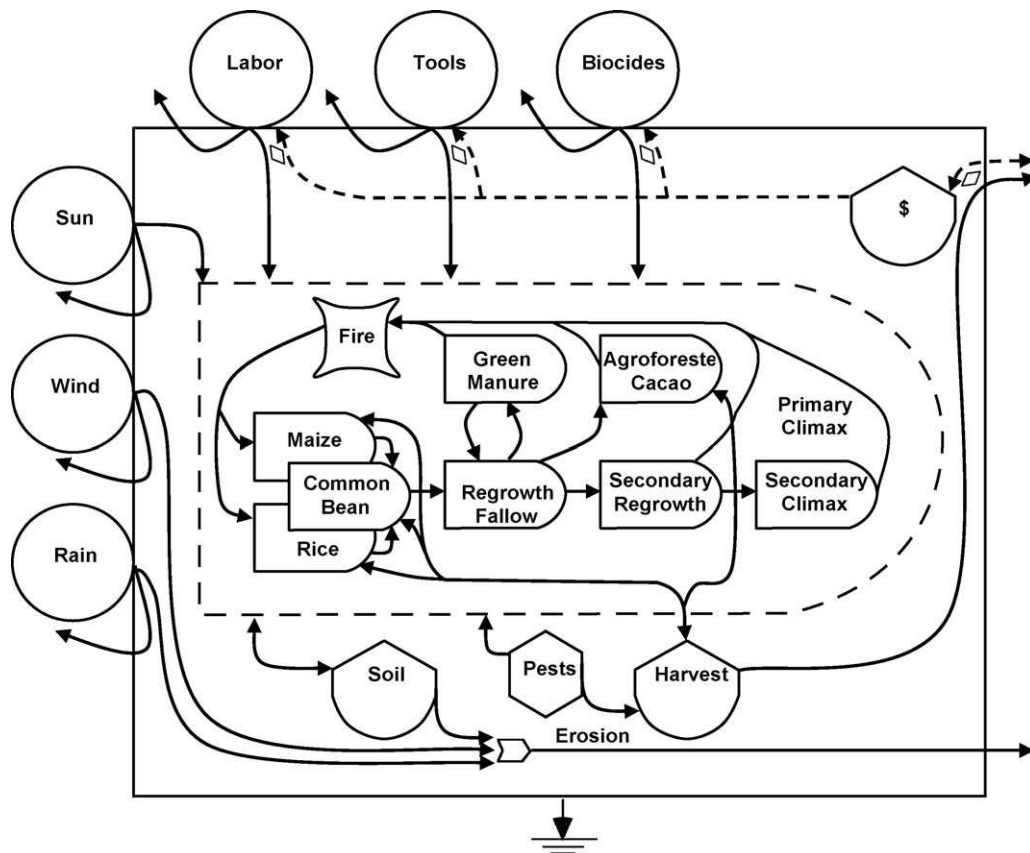


Fig. 3. Agroforestry system diagram of Santa Elena, Belize. Odum (1996) system diagramming is utilized.

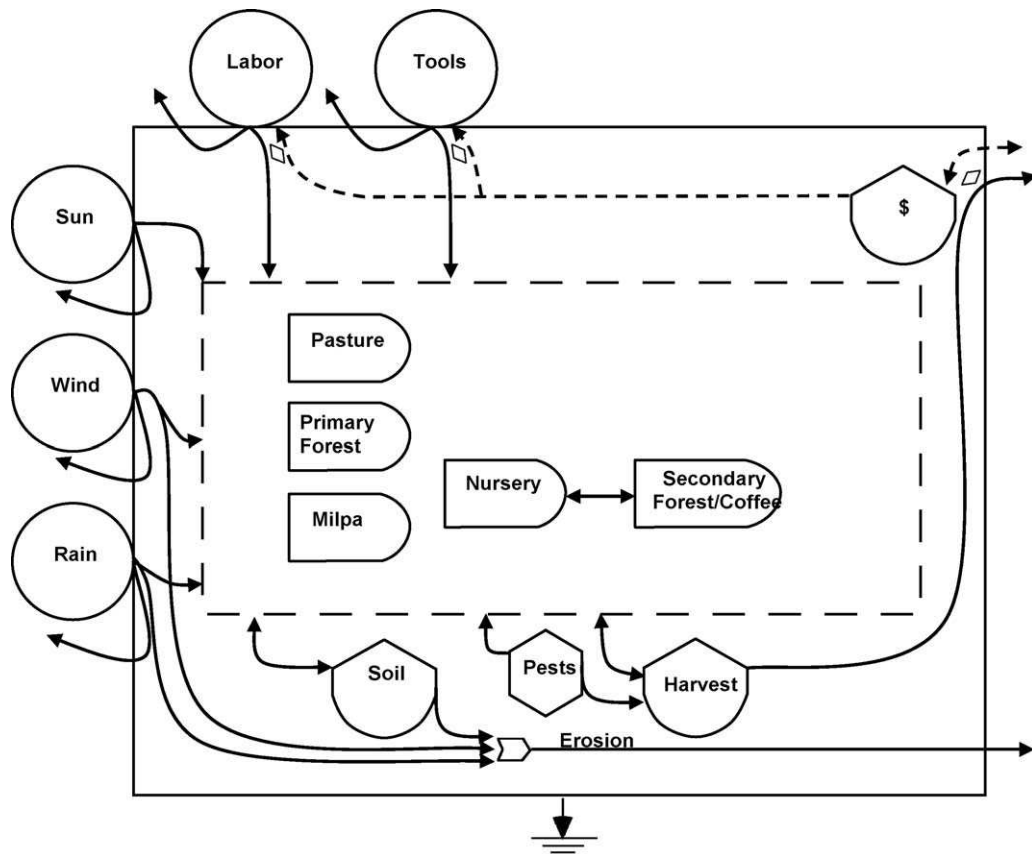


Fig. 4. Production system diagram of Santa Domingo Las Palmas, Mexico. Odum (1996) system diagramming is utilized.

species in this stage. Forest products harvested in the secondary forest include leaves for thatched roofs, timber for homes and furniture, medicines, and wild fruit. As the stage continues to age into *monte* or *selva baja*, reaching maturity at 30 years, the stand structurally resembles areas of primary forest. Yucatec Maya of 20 de Noviembre view this stage as a reserve for future generations to convert to *milpa*, and as a source for income generation through selective logging and *chicle* harvesting. After 30 years the forest is considered *selva alta* (tall jungle), or *selva primaria* (primary forest); it is used for many of the same purposes as the previous stage. Many Yucatec Maya of 20 de Noviembre, Mexico affirm that nurse trees will accelerate succession to *selva alta*, or mature forest. This cycle is repeated with each new *milpa* cleared for food production resulting in family parcels that form a mosaic of the different stages described above.

3.1.2. Nuevo Becal, Mexico–Yucatec Maya and Tsotsil Maya

Controlled burns are used to clear *milpa* sites of 4–5 ha for the traditional crops of corn, beans, squash, and chile; it is the first stage of the Nuevo Becal agroforestry system (Fig. 2 and Table 1). Sites are used for 3–4 years before succession to fallow stages. Three successional stages of fallow, or *yerba*, are recognized, the 5–10 year stage, or *arbusto*, the 10–25 year stage, the *acahual*, and the 25+ stage, *selva alta*, a mature forest structurally indistinguishable from the primary forest, yet recognized by residents as non-primary. In the *arbusto* stage, nurse trees are planted to aid in forest regeneration and to provide for wildlife habitat (see Section 3.2). Firewood and small amounts of home construction material are the main harvestable products in this stage. In the *acahual* stage, no species were planted, but diversity of forest product harvesting was highest. Wood for charcoal production, furniture and woodcrafts, and home building were the dominant products. In the oldest stage,

chicle collection, medicinal plants, and selected timber were the primary products. In addition to swidden agroforestry, home gardens, charcoal production, apiculture, woodcrafts, and a small amount of cattle ranching were utilized by many families.

3.1.3. Santa Elena, Belize – Mopan Maya

The Mopan Maya of Santa Elena, Belize practice a swidden agroforestry system with nine intermittent stages of varying length (Fig. 3 and Table 1). They have a variety of forest stages, including successional regrowth, agroforested areas, and primary forest. The agroforestry system has two herbaceous stages and four forest stages. The system is traditionally initiated with an herbaceous stage, *cux col*, dominated by white corn (*Zea mays* L.) with intermittent *Cucurbita pepo* L. and wild food harvests. *Cux col* is initiated through communal slash and high-intensity, short-duration burn. The brown rice monoculture *cux arroz* is a locally adapted *cux col* variant dominated almost exclusively by upland varieties of *Oryza sativa* L. Following either stage is *cux bo'ole*, a *Phaseolus vulgaris* (bush bean) stage interplanted with garden crops. Following herbaceous stages, the first of two shrub stages, a traditional fallow known as *mehen ca toc*, consists of lightly-managed regrowth. The second shrub stage, *bega*, is a heavily-managed and suppressed form of *mehen ca toc*. This stage includes planted species such as *Pueraria lobata* Willd., *Arachis* spp., and *Mucuna pruriens* L. utilized for shading effects and nitrogen fixation. Lands are left fallow for up to a year and a half, after which time a second corn crop is planted. However, once planted species are established, succession is suspended in *bega* areas for up to five years through biannual clearing. A communal, slash and high-intensity, short-duration burn event allows *bega* to be returned to *cux col* or planted with agroforested crops. Traditionally, stand self-thinning after 12–15 years allows *mehen ca toc* shrub fallow to succeed into secondary regrowth

known as *nuh cux ca toc*. Stands in *nuh cux ca toc* are lightly managed for lumber and fuelwood prior to progression. A modified form of *nuh cux ca toc*, *cux cu'cu'h*, is a heavily-managed agroforested area dominated by planted cacao (*Theobroma* spp.). Cacao are shade-grown with multiple varieties of naturally regenerating *Inga* spp. and planted lumber species such as teak (*Tectona grandis* Linn F.), mahogany (*Swietenia mahagoni* Jacq.), and cedar (*Cedrela* spp.). Timber and wild plant are harvested intermittently for personal use throughout the year. *Cux cu'cu'h* can follow any stage within the system. As stands are thinned and stem dbh values of softwood indicator species surpass 100 cm, secondary regrowth progresses to advanced secondary forest, new *nuk che*. This stage is attained after approximately 20 years since burn event. Mopan also utilize primary forest, known as old *nuk che*, as a commons for selective timber cuts, hunting, and gathering of food, medicines, and firewood.

3.1.4. Santo Domingo las Palmas, Mexico–Tsotsil Maya

The Tsotsil Maya of Santo Domingo las Palmas, Chiapas, Mexico practice various forms of land management, including traditional agroforestry, corn (*milpa*) farming, and cattle ranching, while maintaining surrounding communal forest land (Fig. 4 and Table 1). Coffee agroforestry sites are highly diverse, and all producers interviewed follow certified organic production practices. Key trees used within the coffee agroforestry sites include various *Inga* species *Paterna/Sam* (*Inga paterno* Harms), *Chalum* (*Inga pavoniana* G. Don), *Caspirol* (*Inga punctata* Willd.), which were identified as beneficial for soil fertility and play an integral role in shading the understory of the coffee agroforestry systems. The most common species encountered in the coffee agroforestry sites were *Inga pavoniana* for shade, Cacao (*Theobroma cacao* L.) for sale, and various *Musa* spp. for sale as well. The *milpa* farming and cattle ranching land uses have lower diversity, but are commonly practiced by the Tsotsil Maya of Santo Domingo las Palmas, Chiapas, Mexico.

3.1.5. Lacanja Chansayab, Mexico – Lacandon Maya

The Lacandon Maya divide their agricultural system into primary forest (*taman che*), an herbaceous stage (*kor*—commonly known as *milpa*), two shrub stages (*robir* and *jurup che*—collectively known as *acahual*), and two secondary forest stages (*mehen che* and *nu kux che*) (Diemont and Martin, 2009) (Table 1). *Kor* is the herbaceous stage, a polyculture where upwards of 20 plants are cultivated. How long a field remains in *kor* varies with how often it is tended, ranging from daily to monthly maintenance. More rigorous management will allow land to remain in *kor* for up to 5 years. *Kor* transitions to *robir* (the first fallow shrub stage) when the Lacandon stop weeding herbaceous species, but continue to plant and remove tree species (Adolfo Chan K'in, Lacanja Chansayab, pers. comm.). *Robir* lasts for two years, before the trees mature into *jurup che*, the second fallow shrub stage, which is a 2–3 year phase. Following *jurup che* are two secondary forest stages. The first of the two secondary forest stages is *mehen che*, and the second is *nu kux che*. *Mehen che* lasts for ten years, after which it transitions to *nu kux che*, which can last from five to 20 years. *Taman che* is the Lacandon term for primary forest.

3.2. Native trees for ecosystem restoration

Each community utilized native trees for ecosystem restoration (Table 2). In some cases the seedlings or saplings of these trees were planted and in other cases the seedlings emerged naturally within the plot, and then all of these were protected during management.

Yucatec Maya of 20 de Noviembre, Mexico utilize restoration species or nurse trees in subsistence agroforestry systems within their community. Swidden agroforestry techniques require the regeneration of forest after an area is cleared with a controlled burn

for *milpa* production. They recognize forest regeneration as being important to prevent soil depletion as well as for the support of wildlife. They plant nurse trees five to ten years after a controlled burn to aid in forest regeneration in the previously cleared *milpa* and to prevent grasses and weeds from spreading and competing with forest regeneration. They stated that nurse trees increased the speed at which a mature forest regenerates because the nurse trees helped to create a shady environment for forest trees. Four restoration species were cultivated from seed collected from the surrounding forest: *Swietenia macrophylla* King, *Cedrela odorata* L., *Pimenta dioica* (L.) Merr., and *Hampea trilobata* Standley. After germination in seed beds, emerged seedlings are transplanted randomly at a density of 1–3 trees per 100 m² area, depending on the owner's land resources. Each of the nurse species used is native, relatively fast growing, and moderately shade intolerant, reaffirming their capacity to function as pioneer species in this system. These planted restoration species were also found growing wild in the system; *S. macrophylla* and *C. odorata* were once abundant in the Calakmul area, a 723,185 ha. biosphere reserve in the SE of Campeche, Mexico. Due to over-harvesting primarily by commercial timber companies, these species are relatively rare. Medicinal use, income generation, timber, spice production, and wildlife support are additional uses associated with these four species.

Maya of Nuevo Becal, Mexico accelerate forest regeneration of their swidden agroforestry systems with species useful for restoration. Similarly to the Yucatec Maya of 20 de Noviembre, Mexico, nurse tree species were affirmed to aid in the regeneration of forest after *milpa* production and decrease the amount of time needed for mature forest to reestablish. Species used for restoration include *Brosimum alicastrum* Sw. (Moraceae), *Cedrela odorata*, *Swietenia macrophylla*, *Piscidia piscipula* (L.) Sarg., *Lonchocarpus castilloi* Standl, and *Bursera simaruba* (L.) Sarg. Restoration trees are germinated from seed gathered in the primary forest on community property. Trees are planted five to ten years after a controlled burn. Restoration trees are planted at a density of 2–5 trees per 100 m² area. The factors identified by the Nuevo Becal as to why these species resulted in faster regeneration of a mature forest included: rapid growth, native to the region, and creation of a cooler micro-climate. An additional factor identified in Nuevo Becal was benefit to wildlife and encouragement of bird species that spread the seeds of forest species, promoting greater dispersal into the plot. It was recognized by all community members interviewed that these species were important to the regeneration of the forest and the activity was given high priority in their community.

The species most important for soil and forest restoration in the Mopan Maya community of Santa Elena, Belize are: *Inga* spp. (*b'itz*), *Phyllanthus acidus* (L.) Skeels (*po'ok*, wild plum), *Brosimum alicastrum* (*chic ox*, ramon nut), and an unidentified species called *pu pu te* in Mopan. *B'itz* (*Inga* spp.), also known as the bri bri tree, ice cream bean, and *cho'chok*, are naturally regenerating tree species utilized by the Mopan Maya of Santa Elena in all forest stages. Mopan utilize multiple *b'itz* species for soil restoration, lumber, and fuelwood. The seed pods contain an edible pulp often likened to ice cream in texture, while the seeds are boiled for food. Mopan farmers in Santa Elena often use the leaves of *Brosimum alicastrum*, *Phyllanthus acidus*, and *pu pu te* to increase soil richness. They believe the leaves of these species add nutrients to the soil and increase soil friability. According to Mopan Maya Dionicio Choc these species “...form fertilizer for the ground... makes the soil black, rich...”

Various species were identified by the Tsotsil Maya of Santo Domingo Las Palmas, Mexico as being beneficial for soil fertility in the forest: *Cecropia obtusifolia* Bertol., *Cedrela odorata*, *Croton draco* Schltldl. & Cham., *Inga paterno*, *Inga pavoniana*, *Inga punctata*, and *Schizolobium parahyba* (Vell.) S.F. Blake. Of these species, the three *Inga* species are intentionally planted and all species are protected from removal during regular weeding with machete. The

Inga species are used for firewood and shade in their polyculture agroforestry systems. *Cedrela odorata* is used for the production of fine furniture and is often planted as a shade species in and around coffee agroforestry sites. *C. obtusifolia* and *I. pavoniana* were planted as firewood.

4. Discussion

4.1. Mayan agroforestry systems

The agroforestry systems of 20 de Noviembre, Mexico; Nuevo Becal, Mexico; Santa Elena, Belize; and Santo Domingo Las Palmas, Mexico all bear resemblance to the agroforestry system as practiced by the Lacandon Maya of Lacanja Chansayab, Mexico (see Diemont and Martin, 2009). Community members utilize a variety of successional stages and management areas. They use species for restoring areas in early successional stages to later successional stages and also purposively designed practices or techniques (i.e., transplantation of seedlings or protection of naturally emerged seedlings of the mentioned species) to restore the forest as soon as possible in old *milpa* fields. They obtain a variety of plant and animal products from all stages of succession.

Successional stages and management areas differ among the five groups. The Lacandon Maya, the Yucatec Maya of 20 de Noviembre and the Maya of Nuevo Becal appear to most heavily manage forest succession; these three communities have the most extensive systems of organized forest plantings. The communities of Santo Domingo Las Palmas, Nuevo Becal, and 20 de Noviembre in some cases have arrested succession with cattle ranching. Different motivations likely have driven these land use pattern changes. The Lacandon Maya and the Yucatec Maya are closely related ethnographically (Nations and Nigh, 1980). The Lacandon may have migrated to the Yucatan Peninsula before migrating to Chiapas two to three hundred years ago from the Peten, Guatemala. The Mopan also have similar migration history, likely coming from the Peten, Guatemala, but the Mopan are not in an *ejido* system, where they have some autonomy; they are instead essentially tenants to the Belizean government. Furthermore, the Belizean government taxes the Mopan Maya for fair use of trees. In other words, every time they cut down a tree they must pay a \$15 tax on that tree. Therefore traditional strategies for forest regrowth or grass roots efforts for restoration are disincentivized in the Belizean system of producing marketable products. That said, the Mopan system is the most complex of the systems studied, with the greatest number of recognized successional stages: nine compared to six for the Lacandon, and four in each Yucatec system.

Both the Tsotsil of Santo Domingo Las Palmas and the Yucatec Maya of 20 de Noviembre and Nuevo Becal have pastures to raise cattle. Much of the area surrounding Montes Azules Biosphere Reserve in Chiapas is being converted to cattle ranches. The Santo Domingo community's practice of cattle ranching is therefore not surprising. What is more surprising is that the Lacandon Maya, who also border Montes Azules Biosphere Reserve, do not practice cattle ranching. The Lacandon are the longest permanent residents of the area (Nations and Nigh, 1980; McGee, 2002) and therefore have the longest oral tradition that relates their traditional knowledge to their ecosystem management. In contrast, the Tsotsil Maya of Santo Domingo Las Palmas resemble the vast majority of inhabitants of the area – short term residents, who migrated from different ecoregions to settle in the humid lowland tropical rainforest. The residents of Santo Domingo Las Palmas migrated from upland areas of Chiapas, Chamula, where sheep production is common. They have adapted to the new region with agroforestry; long cycle agroforestry is less common in the upland mountainous areas of Chiapas. Furthermore, in addition to the *milpa*, which

is common in the mountains, they have developed coffee-based agroforestry. The reason for cattle ranching in Nuevo Becal and 20 de Noviembre is less clear. It is likely more related with developing a marketable commodity, ranching incentive programs from government and non-governmental organizations, and movement into *mestizo* lifestyle than Yucatec Maya culturally learned resource use.

Cattle production is not the only form of production for market in these agroforestry systems; coffee production is used by the Tsotsil Maya in Santo Domingo Las Palmas and cacao by the Mopan Maya in Santa Elena. In Santo Domingo Las Palmas, coffee production dominates the agroforestry, and the trees support the coffee through shading. In Santa Elena, the cacao field is a relatively new stage of production, developed during the past two decades, and is incorporated into the larger agroforestry system. Once again the reason for these differences is likely due to adaptation to the area where they are residing. The Mopan Maya have a tradition of over two hundred years in the area, whereas the Tsotsil have resided in the wet lowlands of Chiapas for little over fifty years. Furthermore Tsotsil came from a mountainous area that is geographically distinct from Santo Domingo Las Palmas. Whereas, the Mopan originated in lowland Guatemala and migrated to an area that has similar rainfall and topography to the area they left. The same can be said for the Yucatec of Nuevo Becal, the Yucatec of 20 de Noviembre and the Lacandon of Lacanja Chansayab. In all cases, their history in the larger ecoregion where they currently are located is likely over two hundred years, and perhaps centuries longer. For example, there is little difference in rainfall and precipitation between the Peten, Guatemala and Lacanja Chansayab, Mexico. In the case of the Yucatec Maya, migration was from North to South within Campeche, Mexico and they did not pass through large gradients of precipitation, soil, or climate. In other words, the agroforestry that is being practiced by the Lacandon Maya, the Yucatec Maya, and the Mopan Maya likely has a very long history in its current form.

This connection to place of the Lacandon, Yucatec, and Mopan has been shown to be an important factor in cultural memory. These descendants of ancient culture can more easily maintain and use the tools that are essentially placed in their laps during the childhood and early adulthood. They are appropriate to the ecoregion where they are. The technology transfer is generational but not transcultural or transregional. That they have been less likely to remove traditional forms of their management is likely due most profoundly to its appropriateness to the needs of their ecoregion. In the case of the Tsotsil Maya, they were not first equipped with a long history of traditional ecological knowledge. They therefore rely far more on coffee and cattle than the other Maya groups.

The critical piece of Maya groups with a long history in the ecoregion is forest succession. The Lacandon, Yucatec and Mopan all rely upon and promote successional pathways of their surrounding ecosystem. Like Odum et al. (1963) defined ecological engineering, in the Mayan agroforestry systems human ingenuity is secondary to the ingenuity and design of nature. They plant certain species, but largely rely upon the regenerative capacity of nature. Design and intervention is, however, critical to success, and Mayan agroforestry practices have been designed to maintain and promote the regenerative capacity of forest in their *milpa* old-fields. In the case of all groups restoration species are utilized to accelerate regeneration (Sections 3.2 and 4.2), but that is only a portion of the needs for success. Yucatec Maya relocate bees into fallow areas to both accelerate pollination and honey-making. Lacandon have low intensity burns during early succession. Mopan do considerable clearing during the early stages of the succession. Succession is critical, but like Mitsch and Jorgensen (1989) further defined ecological engineering, humans are really a part of the agro-ecosystem, not apart from the agro-ecosystem at all stages; the ecosystem is a benefit to humans and the ecosystem may benefit from humans. Diemont and Martin (2009), for example, found that structure and some proper-

ties and dynamics of soils in the Lacandon agroforestry advanced secondary forest was similar to primary forest. In Nuevo Becal and 20 de Noviembre Yucatec Maya agroforestry advanced secondary forest does not differ from primary forest in terms of overall bird richness (unpublished data).

4.2. Native trees for ecosystem restoration

In all agroforestry systems, native trees are used for restoration. The system is not left only to rest, instead fallow is often highly managed for regeneration. In the case of the Lacandon over 18 species are used to accelerate regeneration (Table 2, Diemont et al., 2006b). The Yucatec Maya in Nuevo Becal use six species as nurse trees, the Yucatec Maya in 20 de Noviembre four species, and Mopan use ten species (including seven *Inga* species). Although the agroforestry system is not a swidden system, and although they are recent migrants to the area, the Tsotsil Maya of Santo Domingo Las Palmas use seven species for system restoration. Of these species, several are used at multiple sites.

Brosimum alicastrum was found useful for system restoration by the Yucatec Maya in Nuevo Becal and by the Mopan in Santa Elena. An unidentified *Brosimum* sp. (*ba am bax* in Lacandon) was also useful to the Lacandon for restoration. This species, used for fruit, and planted is likely not *B. alicastrum* (*ox* in Lacandon). *B. alicastrum* is planted in both Nuevo Becal and Santa Elena. Interestingly, Sánchez-Velásquez et al. (2004) used nurse trees of different species to assist in reestablishing *B. alicastrum* in Western Mexico forests. Whereas, in southern Mexico in Nuevo Becal, *B. alicastrum* is the nurse tree utilized.

Various *Inga* species are used in both Santo Domingo Las Palmas, Mexico and Santa Elena, Belize. *Inga* spp. is a nitrogen fixer (Rososki, 1982; Nichols et al., 2001), so its inclusion for soil regeneration is not surprising. The two communities that use *Inga* spp. are the two communities that produce coffee and cacao, respectively. *Inga* spp. is a common shade coffee tree in Mesoamerica (Rososki, 1982). In Santa Elena *Inga* spp. is recognized as important in other field areas besides the cacao producing field, such as *mehen ca toc* and *nuh kux ca toc*.

Cedrela odorata is used for system regeneration in all communities except Santa Elena, Belize; however, in Lacanja Chansayab, it was unclear if *Cedrela* sp. was *C. odorata*. Although Yucatec, Tsotsil, and likely Lacandon value *C. odorata* for restoration, Leopold et al. (2001) found survival rates for *C. odorata* in mixed stand restoration in Costa Rica to be only 40%. Griscom et al. (2005) found similar mortality rates for *C. odorata*, 58%, but it was the hardest of the three species they tested in restoration plots in Panama, among *Enterolobium cyclocarpum* and *Copaifera aromatica*.

Swietenia macrophylla is a common species used in degraded sites in Mesoamerica, so its inclusion in plant lists of restoration species in Mayan communities is not surprising. What is surprising due to its slow growth, reaching commercial size in 100 years (Gullison et al., 1996) is that in Yucatec Maya communities, *S. macrophylla* is planted as a nurse species. Both in Nuevo Becal and 20 de Noviembre, *S. macrophylla* is planted in a polyculture of nurse trees that includes faster growing species.

4.3. Mayan land management, restoration and conservation in Mesoamerica

Alcorn (1984), Altieri (1995), Diemont and Martin (2009), and Nations and Nigh (1980), among others, suggest that Mayan ecosystem management and traditional ecological knowledge (TEK) is a way forward for sustainable conservation and restoration in Mesoamerica. Martin et al. (2010) posit that TEK contains many tools for ecological engineering. The research presented in this paper lends further evidence to that idea. At least five Mayan groups

use TEK for conservation of their lands, production for consumption, and restoration of early succession patches to late succession patches. Over thirty tree species are used for restoring ecosystems. Further work is necessary as in Diemont et al. (2006b) and Levy Tacher and Golicher (2004) to understand function of these trees in Mayan restoration. These agroecosystems provide service to the ecosystem, while providing service to humans in terms of multiple products at all stages of succession. Additional research is necessary to understand technology transfer mechanisms that would permit the thousands of migrant communities to learn from the TEK embedded in the area where people settle. Such transfer of knowledge within Mesoamerica could, for example, move the Mesoamerica Biological Corridor closer toward completion.

Acknowledgements

We are grateful for the knowledge shared by community members in Lacanja Chansayab, Chiapas, Mexico; 20 de Noviembre, Campeche, Mexico; Nuevo Becal, Campeche, Mexico; Santa Elena, Toledo District, Belize; and Santo Domingo Las Palmas, Chiapas, Mexico. Financial support from the State University of New York, College of Environmental Science and Forestry and the Syracuse University Program on Latin America and the Caribbean made this research possible.

References

- Alcorn, J.B., 1984. Huastec Mayan Ethnobotany. University of Texas Press, Austin.
- Altieri, M.A., 1995. Agroecology: The Science of Sustainable Agriculture. Westview Press, Inc., Boulder, CO, USA, pp. 433.
- Atran, S., 1993. Itza Maya tropical agroforestry. *Current Anthropology* 34 (5), 633–700.
- Atran, S., 1999. Managing the Maya commons: the value of local knowledge. In: Nzarea, V.D. (Ed.), *Ethnoecology: Situated Knowledge/Located Lives*. University of Arizona Press, Tucson, pp. 190–214.
- Binford, E.M., 2007. Dynamics of land use among Maya of southern Belize. M. A. Thesis, Anthropology, University of Florida, Gainesville, FL, USA.
- Breedlove, D.E., 1973. The phytogeography and vegetation of Chiapas (Mexico). In: Graham, A. (Ed.), *Vegetation and Vegetational History of Northern Latin America*. Elsevier Scientific Publishing, New York, pp. 149–165.
- Campbell, M.S., Anaya, S.J., 2008. The case of the Maya villages of Belize: Reversing the government neglect to secure indigenous land rights. *Human Rights Law Review* 8, 377–399.
- Challenger, A., 1998. Utilización y Conservación de los Ecosistemas Terrestres de México: Pasado, Presente, y Futuro. Instituto de Biología UNAM, Sierra Madre, México.
- CCAD-UND/GEF, 2003. Consolidation of the Mesoamerican Biological Corridor. Managua, Nicaragua.
- De Clerck, F.A.J., Negreros-Castillo, P., 2000. Plant species of traditional Mayan home-gardens of Mexico as analogs for multistrata agroforests. *Agroforestry Systems* 48, 303–317.
- Diemont, S.A.W., Martin, J.F., 2005. Management impacts on the trophic diversity of nematode communities in an indigenous agroforestry system of Chiapas, Mexico. *Pedobiologia* 49, 325–334.
- Diemont, S.A.W., Martin, J.F., Levy-Tacher, S.I., 2006a. Emergy evaluation of Lacandon Maya indigenous swidden agroforestry in Chiapas, Mexico. *Agroforestry Systems* 66, 23–42.
- Diemont, S.A.W., Martin, J.F., Levy-Tacher, S.I., Nigh, R.B., Ramirez-Lopez, P., Golicher, J.D., 2006b. Lacandon Maya forest management: restoration of soil fertility using native tree species. *Ecological Engineering* 28, 205–212.
- Diemont, S.A.W., Martin, J.F., 2009. Lacandon Maya ecological management: a sustainable design for environmental restoration and human subsistence. *Ecological Applications* 19 (1), 254–266.
- Dong, X., Ulgiati, S., Yan, M., Zhang, X., Gao, W., 2008. Energy and emergy evaluation of bioethanol from wheat in Henan Province, China. *Energy Policy* 36, 3882–3892.
- Drew, A., 1999. In: Randolph, G. (Ed.), *Maya ecotourism in the Toledo District of Belize: Benefits and Constraints*. Pack Environmental Institute Occasional Paper 15, Syracuse, NY.
- Emch, M., Quinn, J.W., Peterson, M., Alexander, M., 2005. Forest cover change in the Toledo District, Belize from 1975 to 1999: a remote sensing approach. *The Professional Geographer* 57 (2), 256–267.
- Escamilla, A., SanVicente, M., Sosa, M., Galindo-Leal, C., 2000. Habitat mosaic, wildlife availability and hunting in the tropical forest of Calakmul, Mexico. *Conservation Biology* 14, 1562–1601.
- Ewell, P., Merrill-Sands, D., 1987. Milpa in Yucatán: A long-fallow maize system and its alternatives in the Maya peasant economy. In: Turner I.L., B.L., Bursh, S.B. (Eds.), *Comparative Farming Systems*. Guildford Press, New York, pp. 95–129.

- FAO, 2001. Situación Forestal en la Región-2000, Comisión Forestal para América Latina y el Caribe, Serie Forestal 15. Oficina Regional de la FAO para América Latina y el Caribe, Santiago, Chile.
- Foroughbakhch, F., Hauad, L.A., Cespedes, A.E., Ponce, E.E., Gonzalez, N., 2001. Evaluation of 15 indigenous and introduced species for reforestation and agroforestry in northeastern Mexico. *Agroforestry Systems* 51, 213–221.
- Fox, J., Truong, D.M., Rambo, A.T., Tuyen, N.P., Cuc, L.T., Leisz, S., 2000. Shifting cultivation: a new old paradigm for managing tropical forests. *Bioscience* 50, 521–528.
- Gasser, M., 2006. Machine translation and the future of indigenous languages, I Congreso Internacional de Lenguas y Literaturas Indoamericanas, October, 2006, Temuco, Chile.
- Gomez Pompa, A., Kaus, A., 1999. From pre-hispanic to future conservation alternatives: lessons from Mexico. *Proceedings of the National Academy of Sciences USA* 96, 5982–5986.
- Graham, D., 2003. Mesoamerican Biological Corridor: Mexico to Panama. Global Transboundary Protected Areas Network, Cambridge, United Kingdom.
- Griscom, H.P., Ashton, P.M.S., Berlyn, G.P., 2005. Seedling survival and growth of three native species in pastures: implications for dry forest rehabilitation. *Forest Ecology and Management* 218, 306–318.
- Gullison, R.E., Panfil, S.N., Strouse, J.J., Hubbell, S.P., 1996. Ecology and management of mahogany (*Swietenia macrophylla* King) in the Chimanes Forest, Beni, Bolivia. *Botanical Journal of the Linnean Society* 22 (1), 9–34.
- Harvey, C., Gonzalez Villalobos, J., 2007. Agroforestry systems conserve species-rich but modified assemblages of tropical birds and bats. *Biodiversity and Conservation* 16, 2257–2292.
- Hernandez Castillo, R., Nigh, R., 1998. Global processes and local identity among Mayan coffee growers in Chiapas, Mexico. *American Anthropologist* 100 (1), 136–147.
- Howard, P., Homer-Dixon, T., 1996. Project on environment, population and security. In: *Environmental Scarcity, Violent Conflict: The Case of Chiapas, Mexico*. American Association for the Advancement of Science the University of Toronto, Washington, DC.
- INEGI (Instituto Nacional de Estadística y Geografía Mexico), 2010. www.inegi.org.mx/inegi/default.aspx, (accessed 29.04.2010).
- Kashanipour, R.A., McGee, R.J., 2004. Northern Lacandon Maya medicinal plant use in the communities of Lacanja Chan Sayab and Naha, Chiapas, Mexico. *Journal of Ecological Anthropology* 8, 47–59.
- Kricher, J., 1999. *A Neotropical Companion*. Princeton University Press, New Jersey.
- Lal, R., 1995. Erosion-crop productivity relationships for soils of Africa. *Soil Science Society of America Journal* 59, 661–667.
- Leopold, A.C., Andrus, R., Finkeldey, A., Knowles, D., 2001. Attempting restoration of wet tropical forests in Costa Rica. *Forest Ecology and Management* 142, 243–249.
- Levy Tacher, S.I., Aguirre, J.R., Martinez Romero, M.M., Duran Fernandez, A., 2002. Caracterización del uso tradicional de la flora espontánea en la comunidad Lacandona de Lacanja, Chiapas, Mexico. *Interciencia* 27, 512–520.
- Levy Tacher, S., Hernández, X.E., García, M.E., Castillo, M.A., 1991. Sucesión secundaria bajo roza-tumba-quema en Yucatán. *Agrociencia (Ser. Rec. Nat. Ren.)* 1 (3), 7–24.
- Levy Tacher, S.I., Golicher, J.D., 2004. How predictive is traditional ecological knowledge? The case of the Lacandon Maya fallow enrichment system. *Interciencia* 29, 496–503.
- Li, W.H., 2004. Degradation and restoration of forest ecosystems in China. *Forest Ecology and Management* 201, 33–41.
- Long, A.J., Nair, P.K.R., 1999. Trees outside forests: agro-, community, and urban forestry. *New Forests* 17, 145–174.
- Martin, J.F., Roy, E.D., Diemont, S.A.W., Ferguson, B.G., 2010. Traditional ecological knowledge (TEK): Ideas, inspiration, and designs for ecological engineering. *Ecological Engineering* 36 (7), 839–849.
- McGee, R.J., 2002. *Watching Lacandon Maya*. Allyn and Bacon, Boston.
- Mitsch, W.J., Jorgensen, S.E., 1989. *Ecological Engineering: An Introduction to Ecotechnology*. John Wiley & Sons, New York.
- Nations, J.D., Komer, D.I., 1983. Central America's tropical rain forests: positive steps for survival. *Ambio* 12, 232–238.
- Nations, J.D., Nigh, R.B., 1980. The evolutionary potential of Lacandon Maya sustained-yield tropical forest agriculture. *Journal of Anthropological Research* 36, 1–30.
- Nichols, J.D., Rosemeyer, M.E., Carpenter, F.L., Kettler, J., 2001. Intercropping legume trees with native timber trees rapidly restores cover to eroded tropical pasture without fertilization. *Forest Ecology and Management* 152, 195–209.
- Nicholson, C.F., Blake, R.W., Lee, D.R., 1995. Livestock, deforestation, and policy making—intensification of cattle production systems in Central-America revisited. *Journal of Dairy Science* 78, 719–734.
- Odum, H.T., Siler, W.L., Beyers, R.J., Armstrong, N., 1963. Experiments with Engineering of Marine Ecosystems, vol. 9. Publications of the Institute of Marine Science, p. 373–403.
- Odum, H.T., 1996. *Environmental Accounting: Emergy and Environmental Decision Making*. Wiley, New York.
- Plotkin, M.J., 1988. The outlook for new agricultural and industrial products from the tropics. In: Wilson, E.O. (Ed.), *Biodiversity*. National Academy Press, Washington, pp. 106–116.
- Quintana-Ascencio, P.F., Gonzalez-Espinosa, M., Ramirez-Marcial, N., Dominguez-Vazquez, G., Martinez-Ico, M., 1996. Soil seed bank and regeneration of tropical rain forest from *milpa* fields at the Selva Lacandona, Chiapas, Mexico. *Biotropica* 28 (2), 192–209.
- Ram, R., 1997. Tropics and economic development: an empirical investigation. *World Development* 25, 1443–1452.
- Ray, D.K., Welch, R.M., Lawton, R.O., Nair, U.S., 2006. Dry season clouds and rainfall in northern Central America: implications for the Mesoamerican Biological Corridor. *Global and Planetary Change* 54, 150–162.
- Rivera, V.S., Cordero, P.M., Cruz, I.A., Borras, M.F., 2002. The mesoamerican biological corridor and local participation. *Parks* 12, 42–54.
- Roskoski, J.P., 1982. Nitrogen fixation in Mexican coffee plantation. In: Robertson, G.P., Herrera, Rosswail, T. (Eds.), *Nitrogen Cycling in Ecosystems of Latin America and the Caribbean*. Nijhoff, The Hague, pp. 283–292.
- Salafsky, N., 1993. Mammalian use of a buffer zone agroforestry system bordering Gunung Palung National Park, West Kalimantan, Indonesia. *Conservation Biology* 7, 928–933.
- Sánchez-Velásquez, L.R., Quintero-Gradilla, S., Aragón-Cruz, F., Pineda-López, M.R., 2004. Nurses for *Brosimum alicastrum* reintroduction in secondary tropical dry forest. *Forest Ecology and Management* Volume 198 (1–3), 401–404.
- Sharer, R.J., Traxler, L.P., 2006. *The Ancient Maya*, 6th Ed. Stanford University Press, Palo Alto, California.
- Tremblay, M., 1957. The key informant technique: a non-ethnographic application. *American Anthropologist* 59 (4), 688–701.
- Tucker, C.M., Munroe, D.K., Nagendra, H., Southworth, J., 2005. Comparative spatial analyses of forest conservation and change in Honduras and Guatemala. *Conservation and Society* 3 (1), 174–200.
- Wang, Z.J., Young, S.S., 2003. Differences in bird diversity between two swidden agricultural sites in mountainous terrain, Xishuangbanna, Yunnan, China. *Biological Conservation* 110, 231–243.